Relativistic effects in Large Scale Structure

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University of Edinburgh, July 24th, 2017

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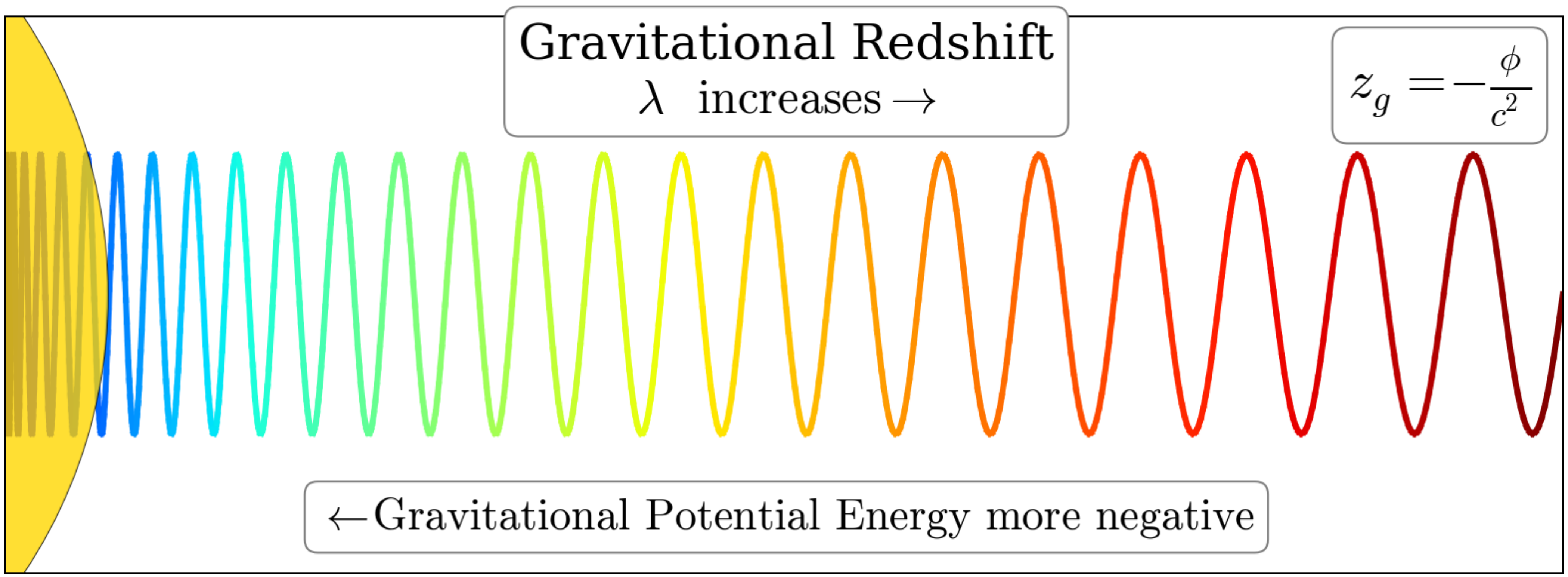
Advances in theoretical cosmology in light of data,
NORDITA, Stockholm

What will you experience.

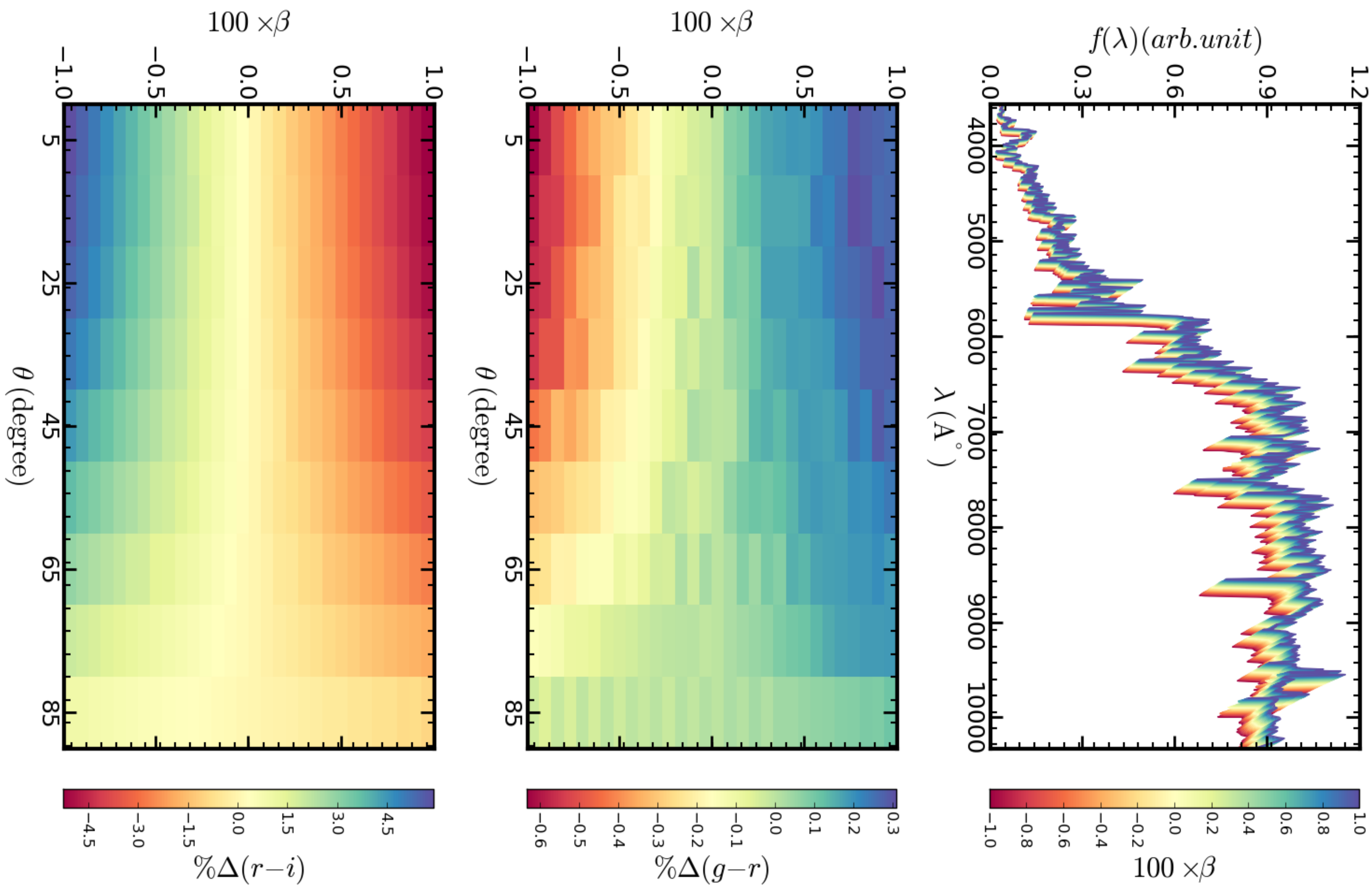
- A quick reminder to few dominant effects.
- How do they affect measurement?
- How can we possibly measure them?
- What does N-body simulations predicts?
- Can we measure any signature in current data?
- Let there be light with a summary!!

Reminder to few Relativistic effects

1) Gravitational Redshift



2) Special Relativistic Beaming



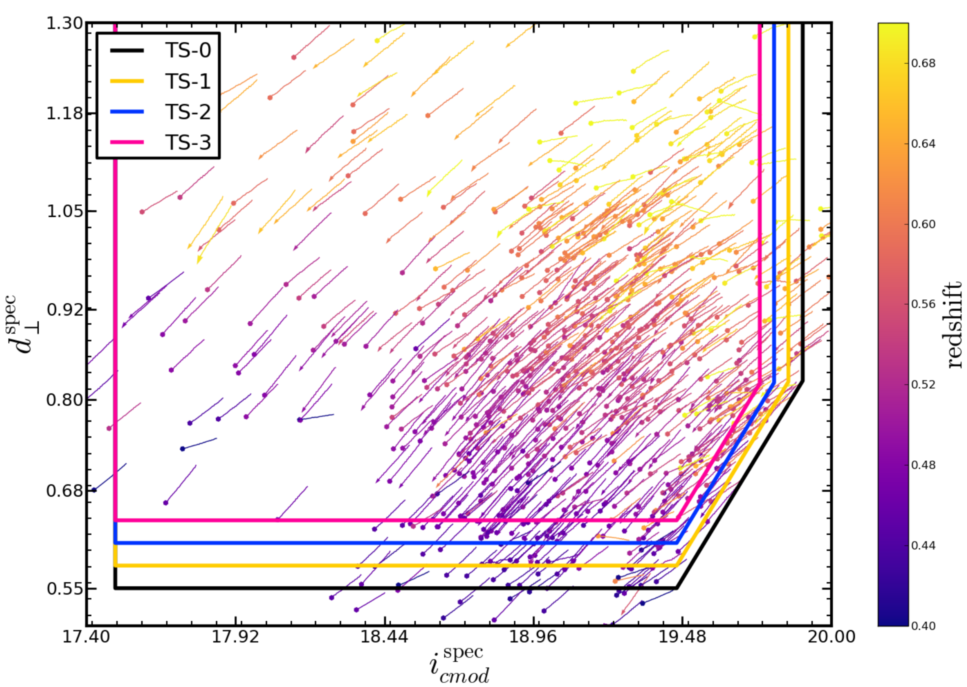
S. Alam, R.A.C. Croft, S. Ho, H. Zhu, E. Giusarma , MNRAS (2017)

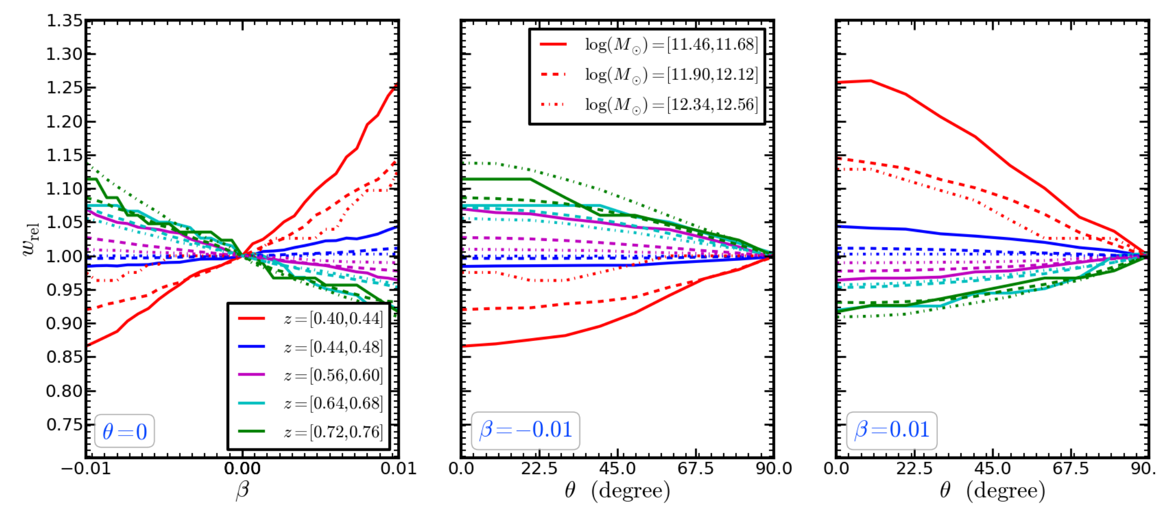
https://doi.org/10.1093/mnras/stx1684

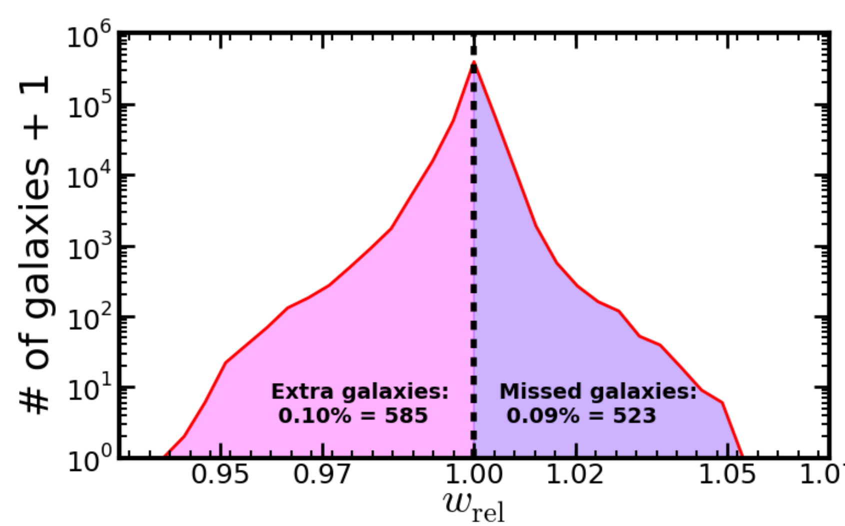
2) Special Relativistic Beaming (continued)

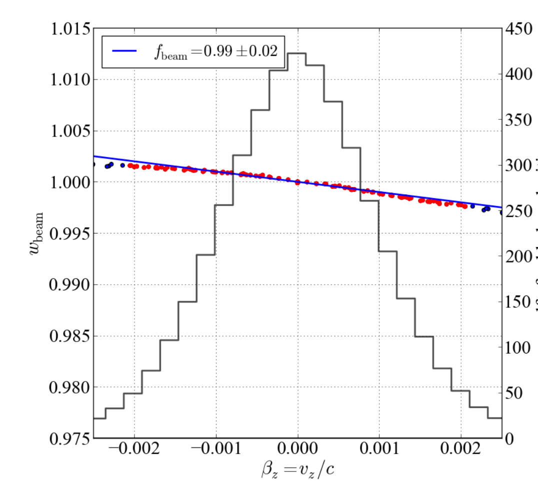
Depends on details galaxy SED, redshift, survey selection, and key galaxy properties.

We have worked out SRB for SDSS-III CMASS sample.
See: Alam et. al. (2017), https://doi.org/10.1093/mnras/stx1684









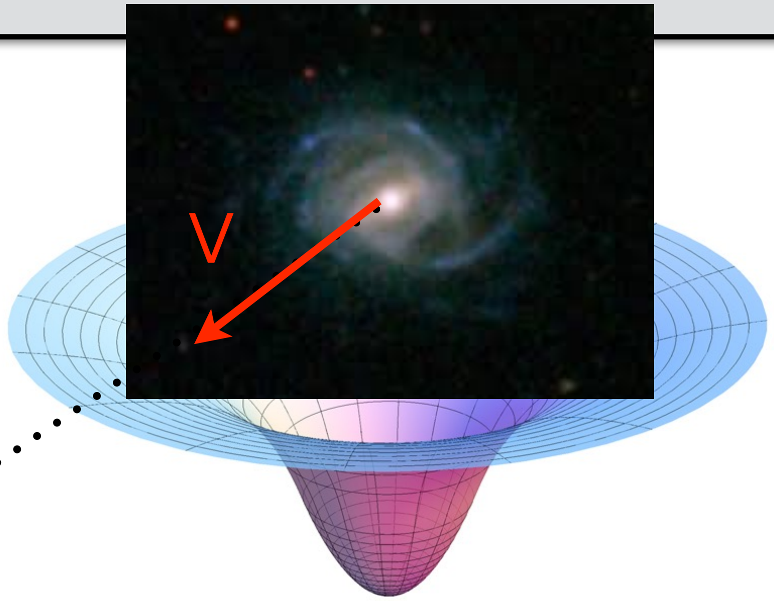
3) Many Other effects

- Transverse doppler effect
- Light Cone
- Luminosity distance perturbation
- Wide-angle effects
- Second order cross-terms in the expansion of redshift.

See Zhu et. al. (2017) for more details:
HZ, **SA**, RAC, SH, EG, MNRAS (2017): **stx1644**
https://doi.org/10.1093/mnras/stx1644

Interesting!!
But, what can we do with these effects?

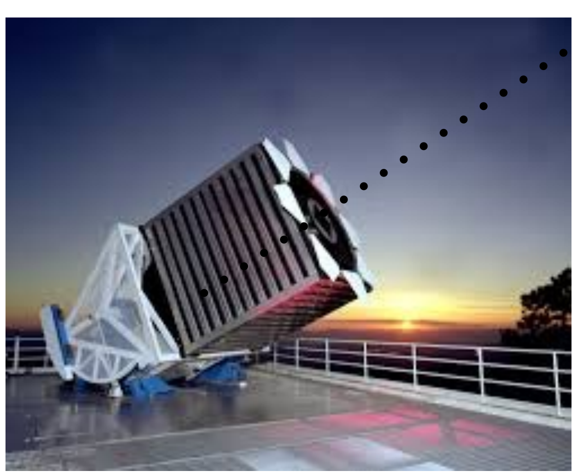
The Redshift



$$z_{\rm obs} = H(z)r/c + v_{\rm pec}/c + z_g + \ldots$$

RSD

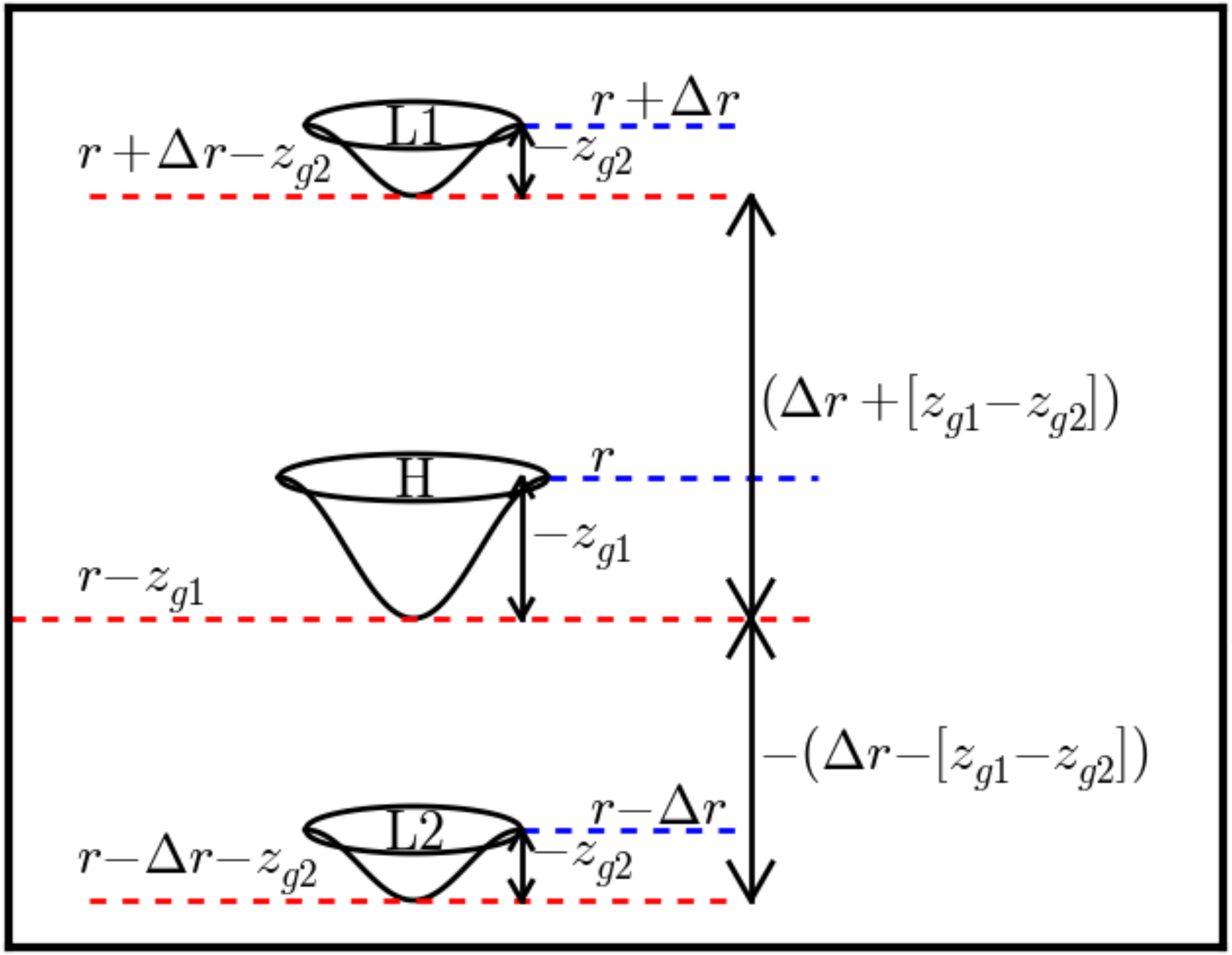
Gravitational Redshift



But we don't know the true distance to galaxy?

How about differential measurement!

Relativistic Effects in LSS



Cross Correlation saves the day again!!

SA, HZ, RAC, SH, EG, **Measurement of Gravitational Redshift**, MNRAS (2017) **470 (3): 2822-2833**

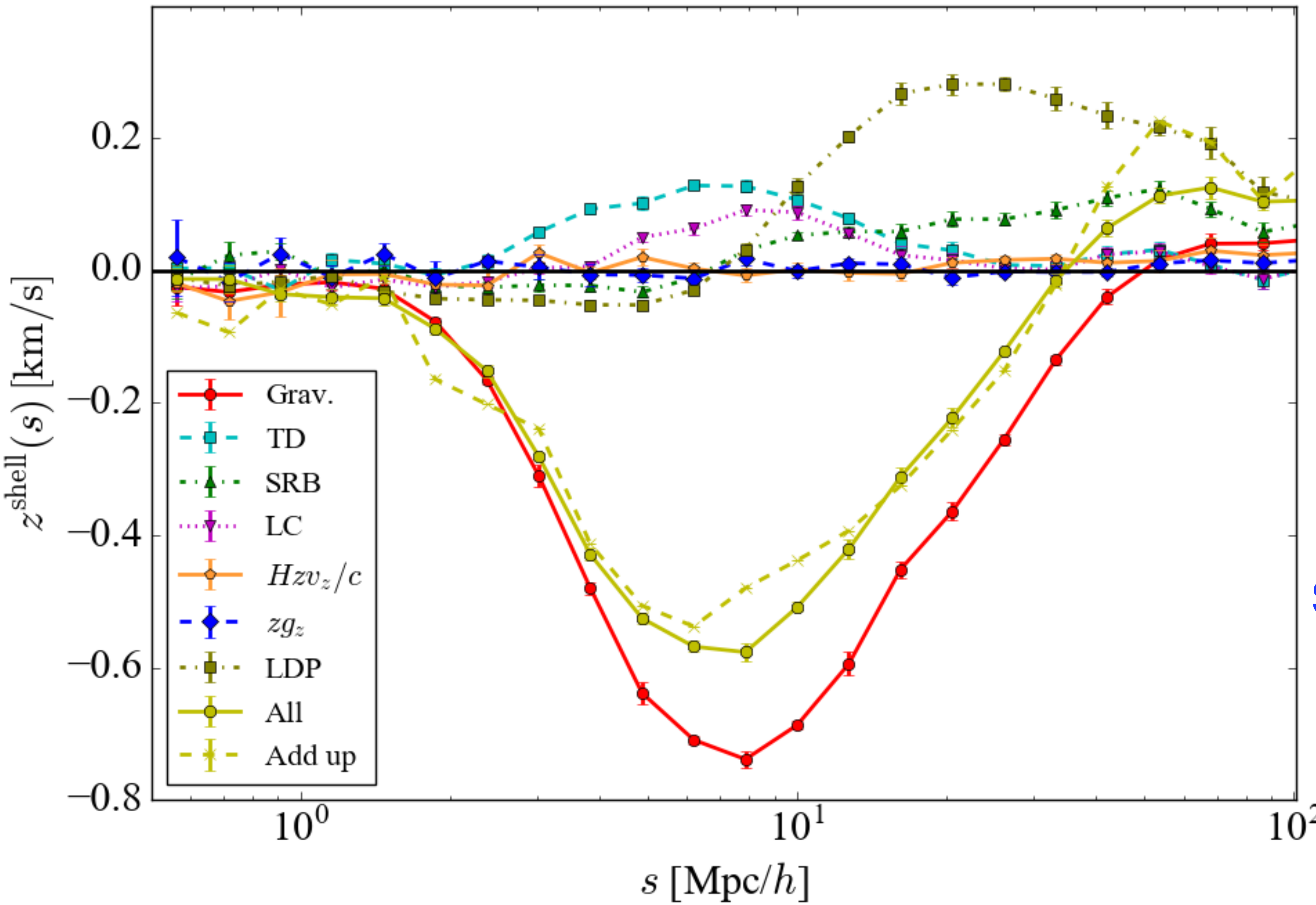
Shell Estimator

$$z_g^{shell}(r) = \frac{\int_{\theta=0}^{\theta=\pi} H r_{\|} [1+\xi(r,\theta)] d\theta}{\int_{\theta=0}^{\theta=\pi} [1+\xi(r,\theta)] r dr d\theta}$$

Cross-Correlation of galaxy sub-sample with different bias

R.A.C. Croft, MNRAS (2013), 434, 3008

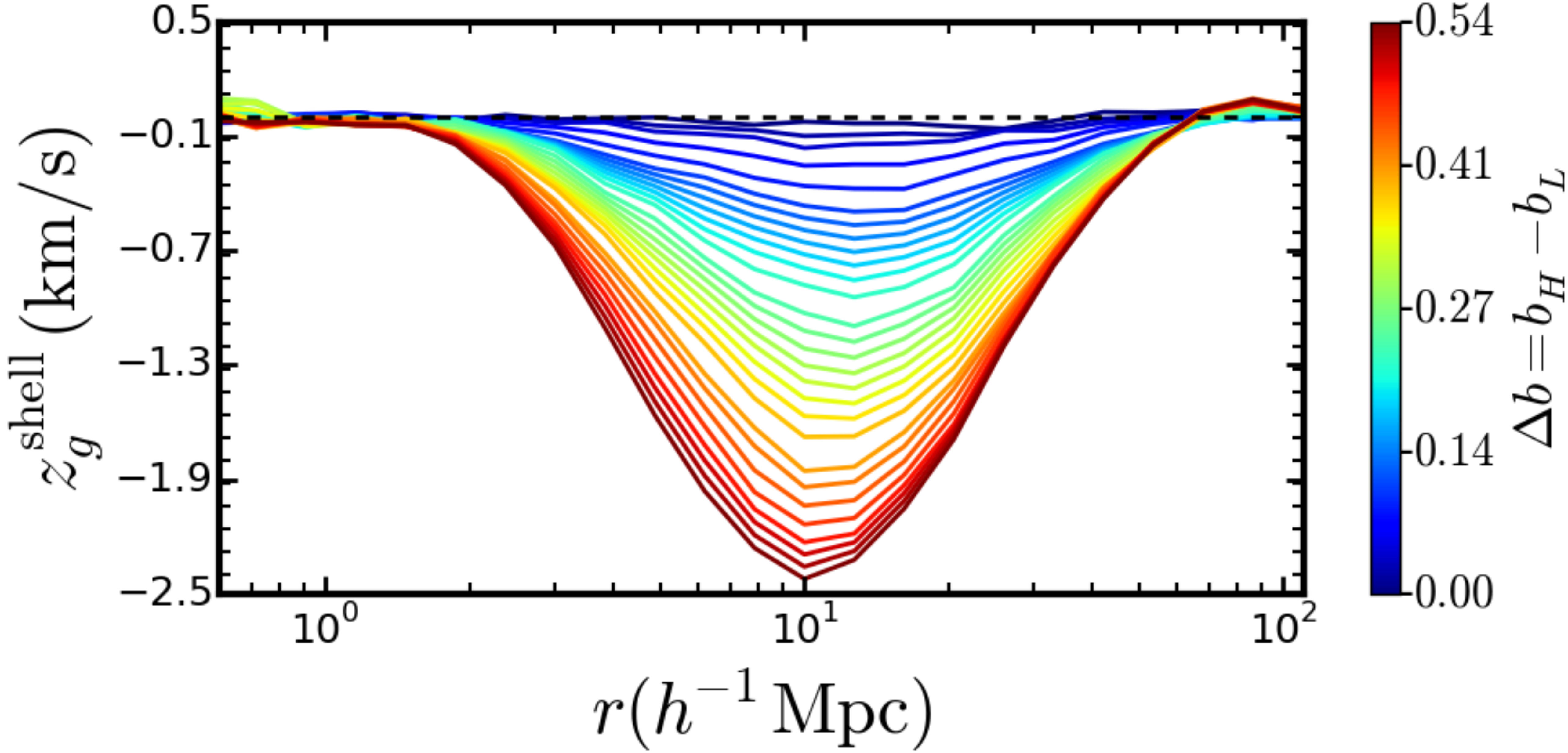
In N-body Simulation



Notice the additive nature of shell estimator

HZ, **SA**, RAC, SH, EG, **Relativistic effects in N-body simulations,** MNRAS (2017) **stx1644**

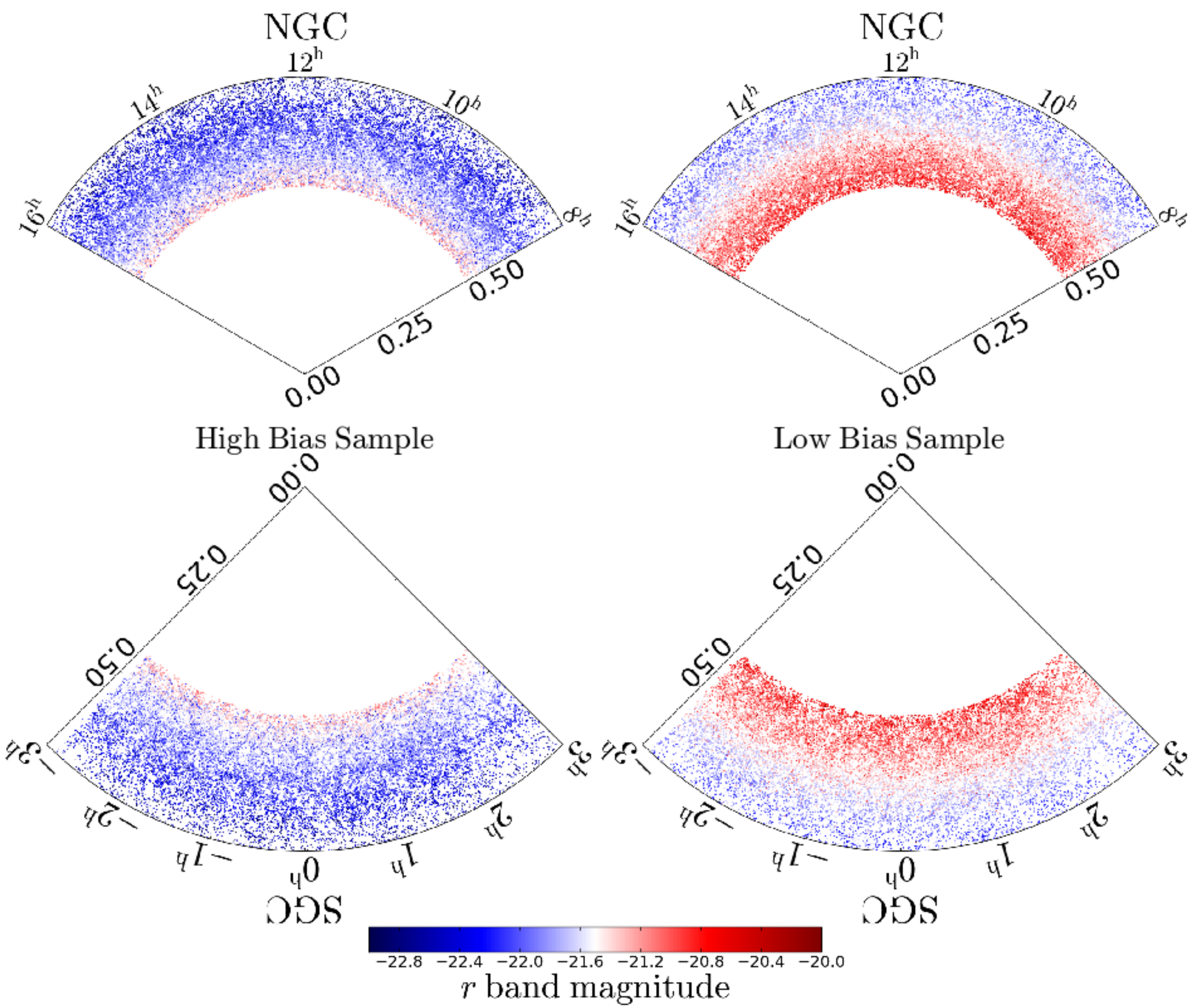
Function of bias difference



SA, HZ, RAC, SH, EG, **Measurement of Gravitational Redshift**, MNRAS (2017) **470 (3): 2822-2833**

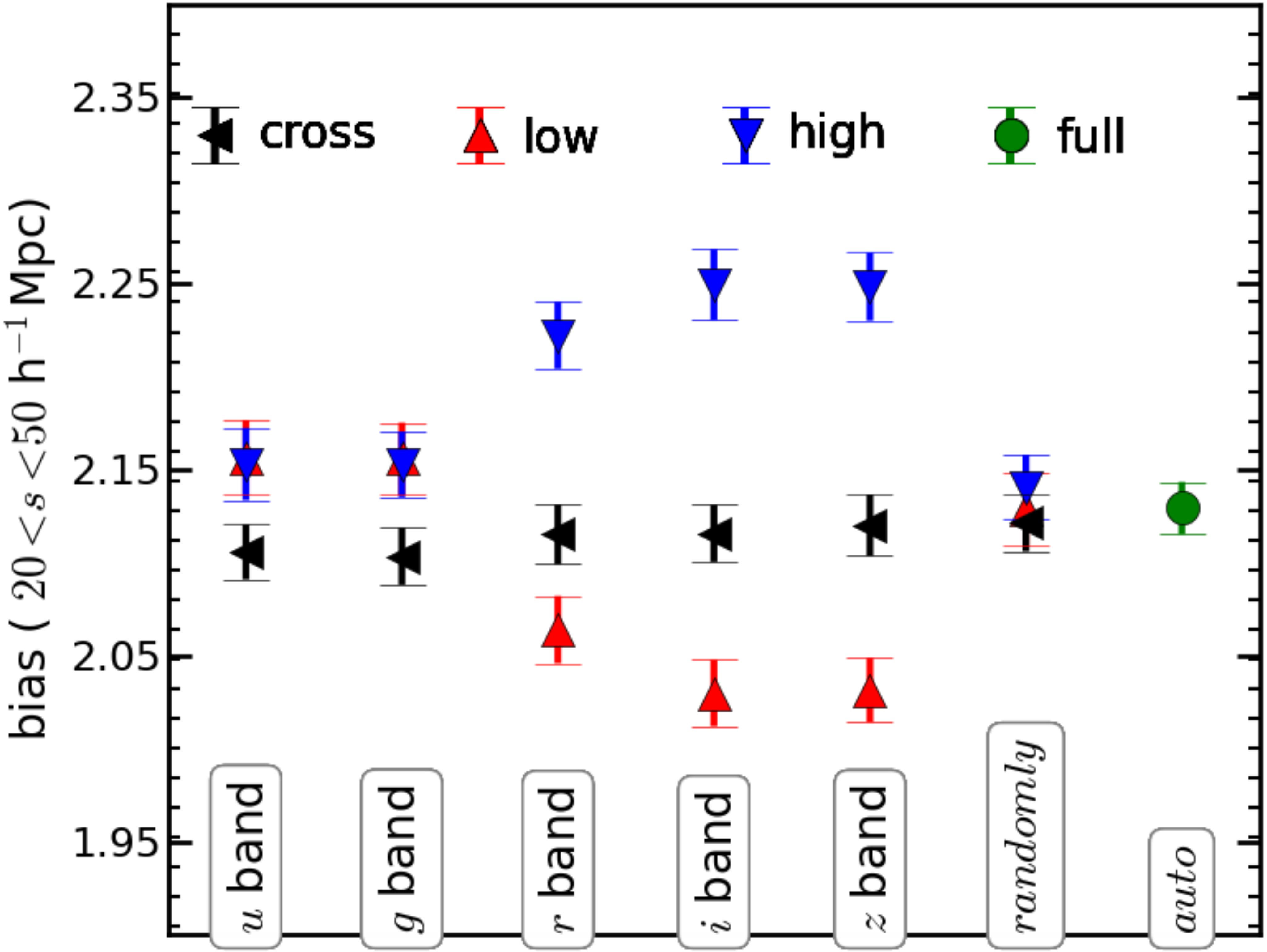
Measurement in SDSS

Galaxy Sub-samples



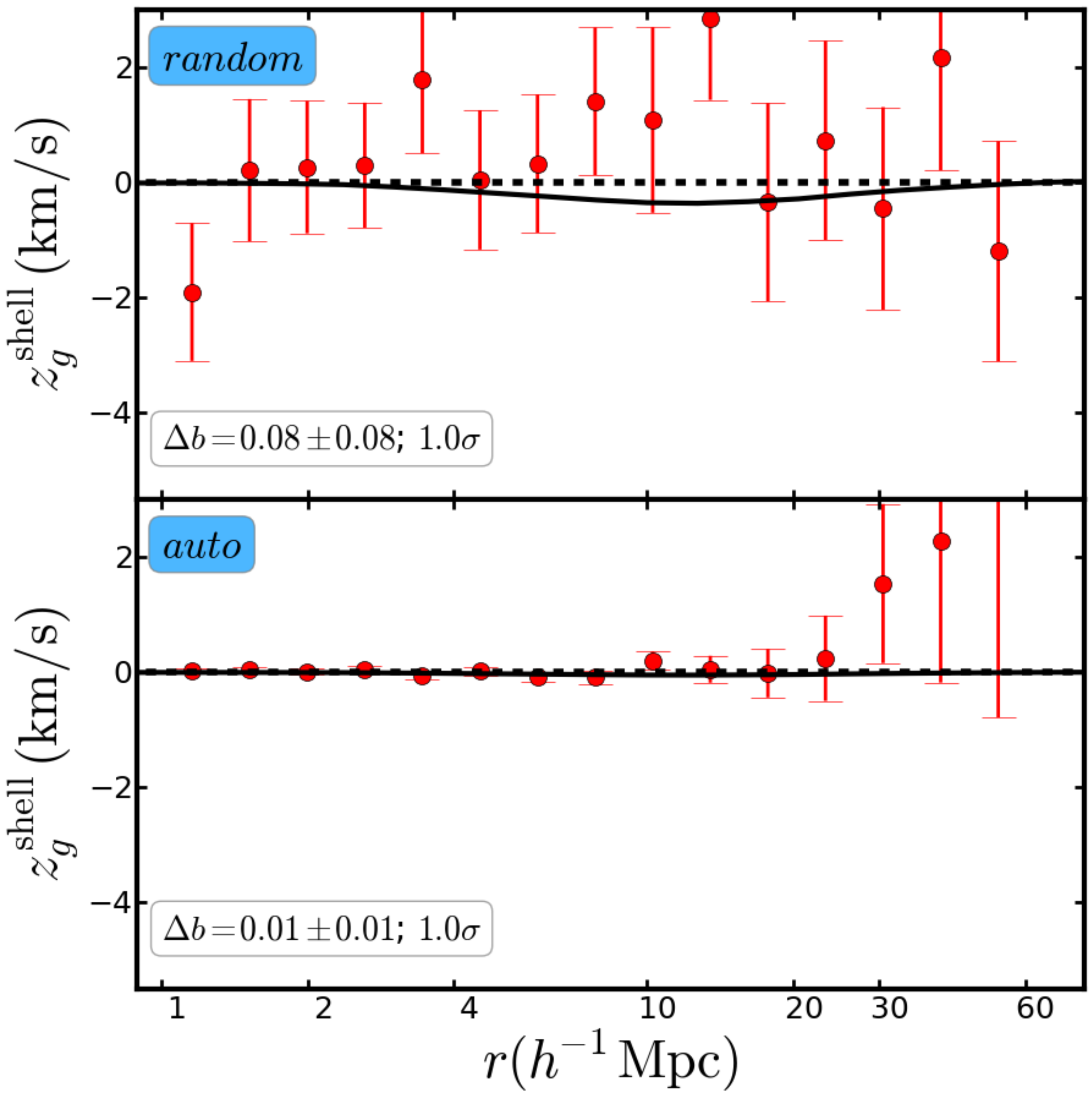
SA, HZ, RAC, SH, EG, **Measurement of Gravitational Redshift**, MNRAS (2017) **470 (3): 2822-2833**

Galaxy Bias



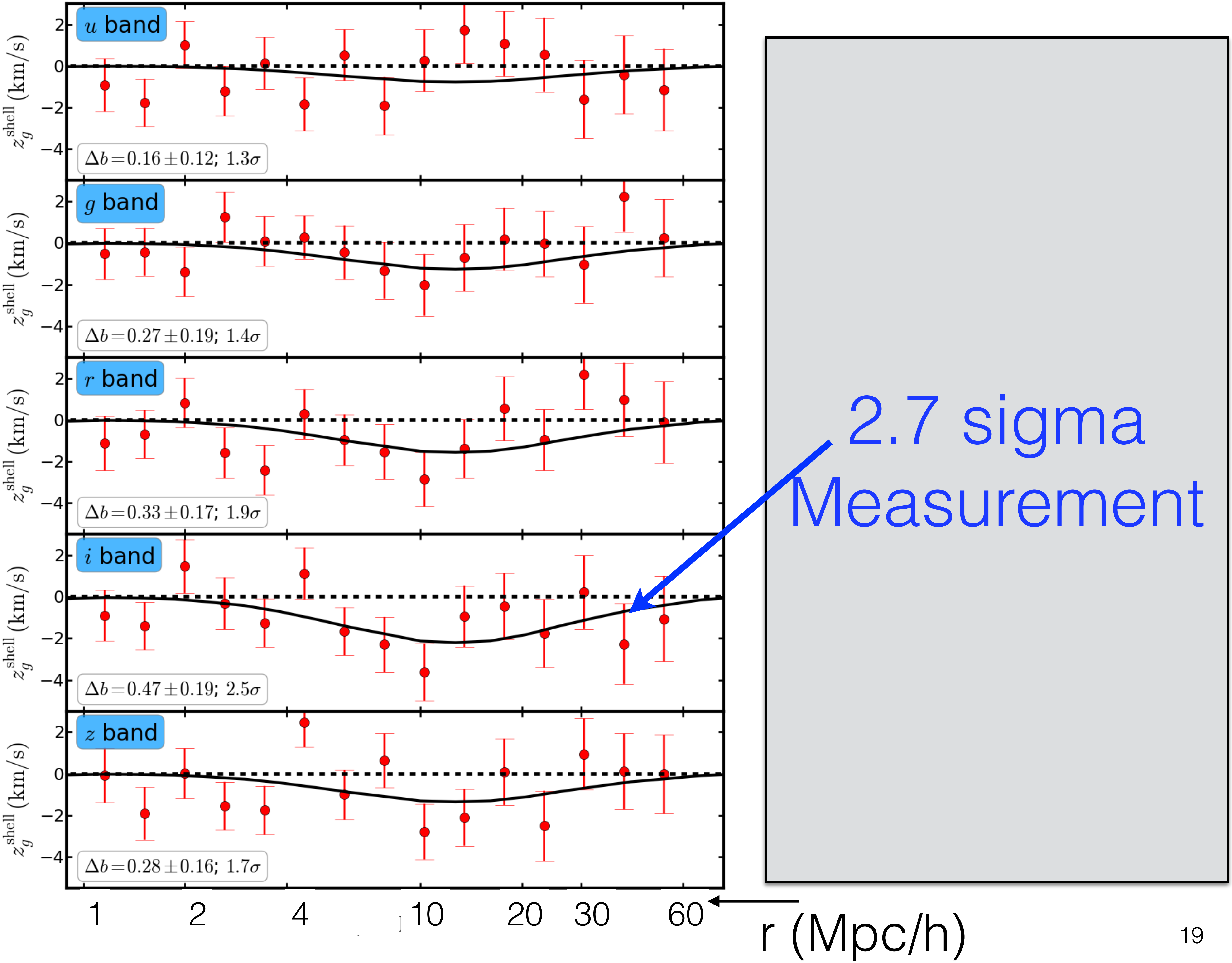
cross
low
high
full
bias (20 < s < 50 h⁻¹ Mpc)
2.35
2.25
2.15
2.05
1.95
u band
g band
r band
i band
z band
randomly
auto

Can We measure this effect?



Null tests.

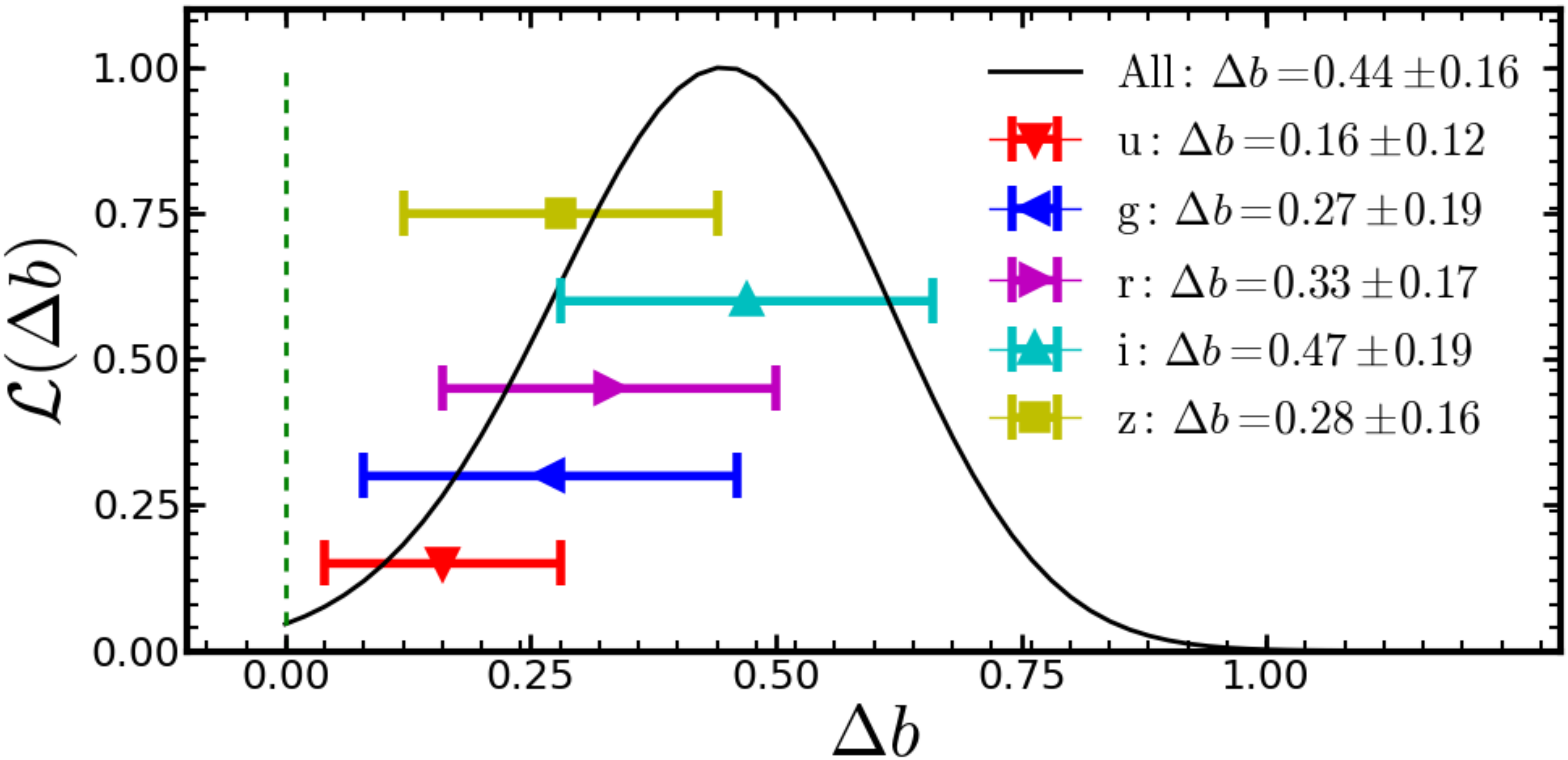
No Signal!!



u band
g band
r band
i band
z band
$z_g^{\rm shell}$ (km/s)
$\Delta b = 0.16 \pm 0.12$; 1.3σ
$\Delta b = 0.27 \pm 0.19$; 1.4σ
$\Delta b = 0.33 \pm 0.17$; 1.9σ
$\Delta b = 0.47 \pm 0.19$; 2.5σ
$\Delta b = 0.28 \pm 0.16$; 1.7σ
2.7 sigma Measurement
r (Mpc/h)

Can We measure this effect?

Almost!! 2.7 sigma Measurement



Take Home

Rich Physics: There are several interesting signatures of General Relativity which depends on details of gravitational potential and its interaction with photon.

Magnifying glass for dark matter: New opportunity to study the details of halo potential and will possibly provide a magnifying glass to study the dark matter through such phenomenon.

Rising above the noise floor: The planned survey are fantastic to do precision cosmology but will also lower the noise floor below the measurement limit of these effects.

Future of extended halo scale gravity tests: These will also be first detection of such effects on cosmological scales and might become the frontier of testing modified gravity. Failure to measure these will also provide interesting insight into the true nature of gravity.

Thanks to

COSFORM erc NSF NORDITA

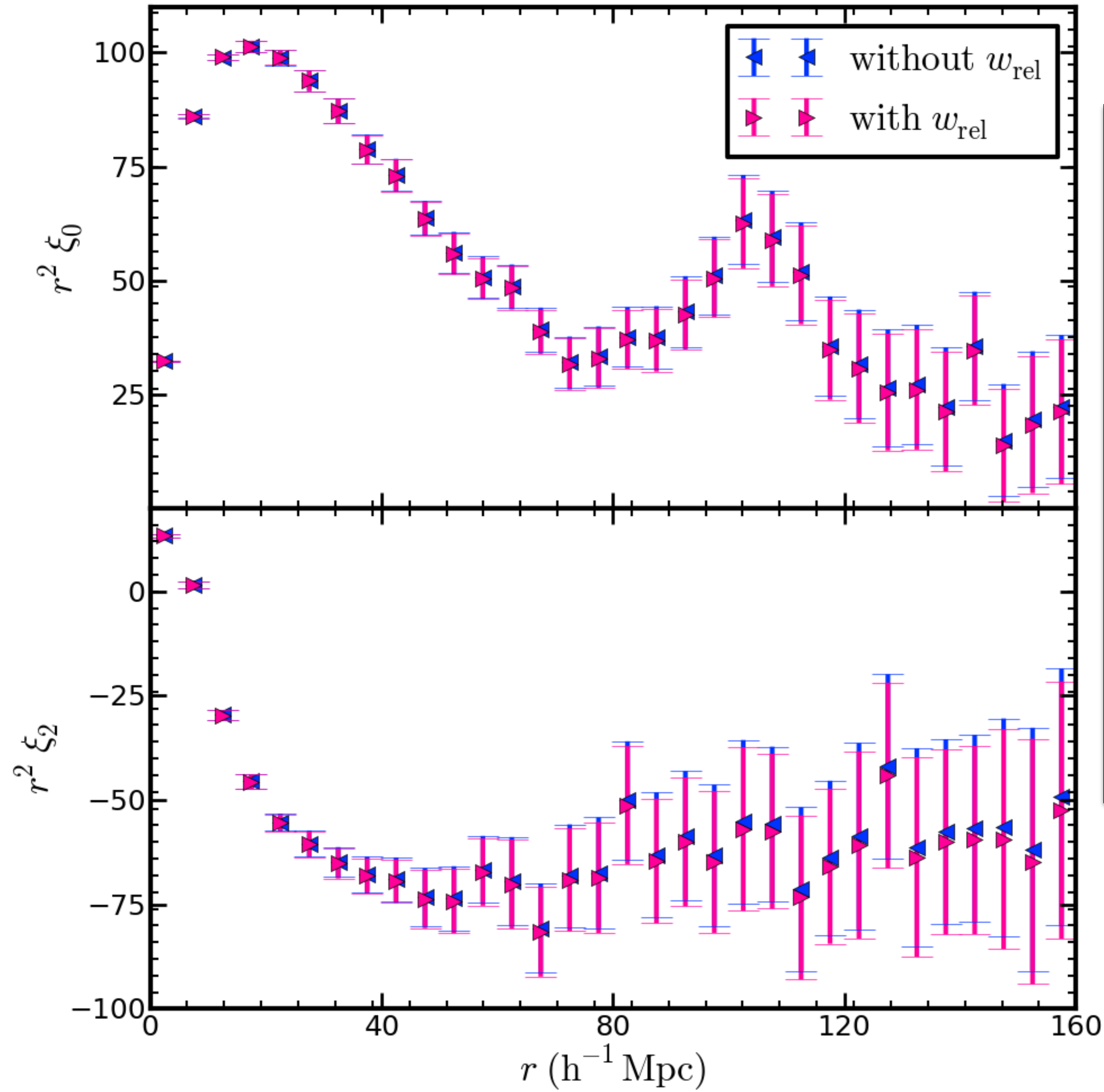
Published papers:

Measurements: **SA**, HZ, RAC, SH, EG, MNRAS (2017) **470 (3): 2822-2833**
Modeling in N-body: HZ, **SA**, RAC, SH, EG, MNRAS (2017) **stx1644**
SRB: **SA**, RAC, SH, HZ, EG , MNRAS (2017) **stx1684**

In Preparation:

Modeling in Perturbation theory: EG, **SA**, HZ,RAC,SH, (in prep.)
See Elena's talk on Tuesday at 12:00!

Questions?



The galaxy clustering shows negligible effects